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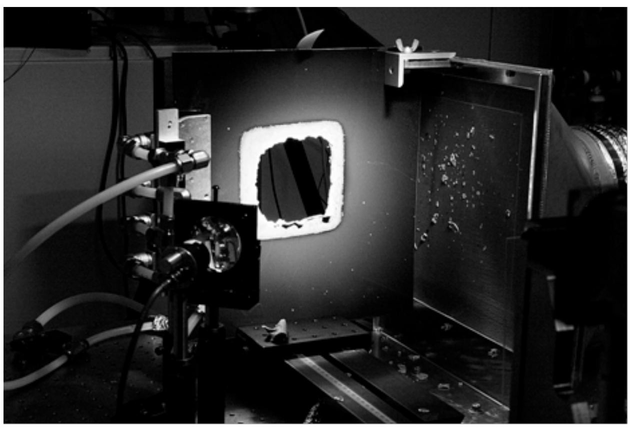
INTRODUCTION

A variety of laser-material interaction experiments have been conducted at Lawrence Livermore National Laboratory (LLNL) utilizing the solid-state heat capacity laser (SSHCL). For these series of experiments, laser output power is 25kW, on-target laser spot sizes of up to 16 cm by 16 cm square, with air speeds of approximately 100 meters per second flowing across the laser-target interaction surface as shown in Figure 1. The empirical results obtained are used to validate our simulation models.



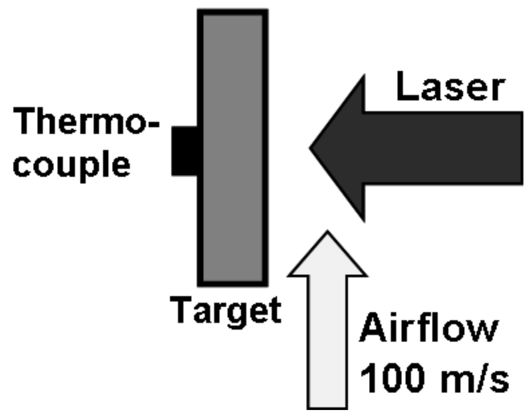


Figure 1. Experimental test setup and schematic representation

LASER-MATERIAL INTERACTION EXPERIMENTS

The work described formulates LLNL's integrated science approach to understanding vulnerability: theory of interaction, simulation and experimental testing. During the course of this modeling/experimental campaign, we evaluated several target destruction methods over a range of operational parameters and material types. This work combines our modeling expertise and know-how with our real-world experimental capability, which utilizes relevant power density and laser on-target spot sizes. Results from these system studies are presented and include the following target destruction methods:

I. Rapid material removal enhanced by combustion (drilling/ablation):

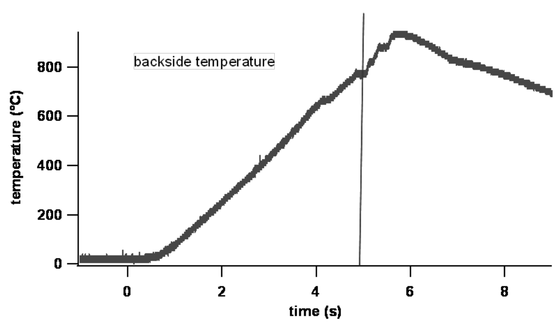
   Experiments were conducted of laser interaction on steel targets, initially in a static configuration. The data is represented by the term Q*, the amount of energy required to remove 1 gram of material. Subsequent experiments included a high stream of air flowing across the laser-target interaction area to more closely portray actual target scenarios. These experiments are related to the use of directed energy weapons as a defense against RAM (rockets, artillery and mortars) and demonstrate the essential role of combustion in enhancing target destruction. The airflow removes the oxide layer on the surface of the target, greatly increasing the combustion process and the removal of material.

Knowing this, the parameter of airflow is an important variable required for determining accurate lethality estimates.

Figure 2. 1” thick steel target, 2.5 cm square spot size, 10 second run time

II Rapid “Cook-off” (explosive initiation via heat conduction):

The destruction mechanism for a mortar or Katyusha rocket is referred to as “rapid cook-off”. In this scenario, the high explosive in the interior of the target is detonated/deflagrated when it reaches its critical temperature. This reaction is brought about by the laser beam heating a large spot on the outside of the target, resulting in heat being conducted through the casing and rapidly heating the high explosive residing within. In this example, it is clear that the initiation process is not directly related to material removal Q* (as described in the first example), but by the temperature rise of the target body.



Test Parameters:

SSHCL average power: 27 kW
Laser “on” time: 5 seconds
Beam size: 2.8 cm by 2.8 cm
Mortar wall thickness > 1 cm in spot location
224 mph air blowing across mortar surface
Non-spinning mortar

Inside wall temperature exceeds 700 deg C after 5 seconds of laze time, adequate to initiate the mortar’s high explosive

Figure 3. 82 mm mortar with corresponding inside surface temperature rate of rise

III. Aerodynamic imbalance due to air flow interaction:

Experiments conducted on thin sheets of aluminum, again with a stream of air flowing across the laser-material interaction region, demonstrate that well before melting of the aluminum material, the material softens and then bulges outward due to the low-pressure region formed by the flowing air. The hydrodynamic force generated by the stream of flowing air is sufficient to rip away the aluminum material. This dynamic interaction with the airflow breaks up the target, providing the conclusion that target lethality is determined not only by laser effects, but also by the affect of the airflow stream (wind) on the target.

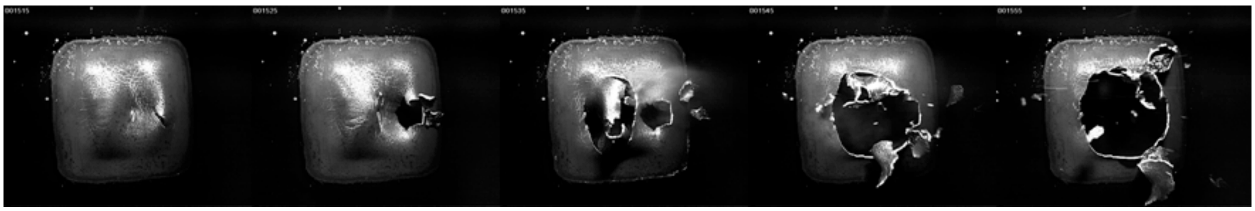


Figure 4. Laser – material interaction: 25 kW laser on a thin aluminum sheet, 13 cm by 13 cm spot size, 100 meter/sec air flow (left to right), 0.07 seconds total elapsed time starting at 2.53 seconds into the run.

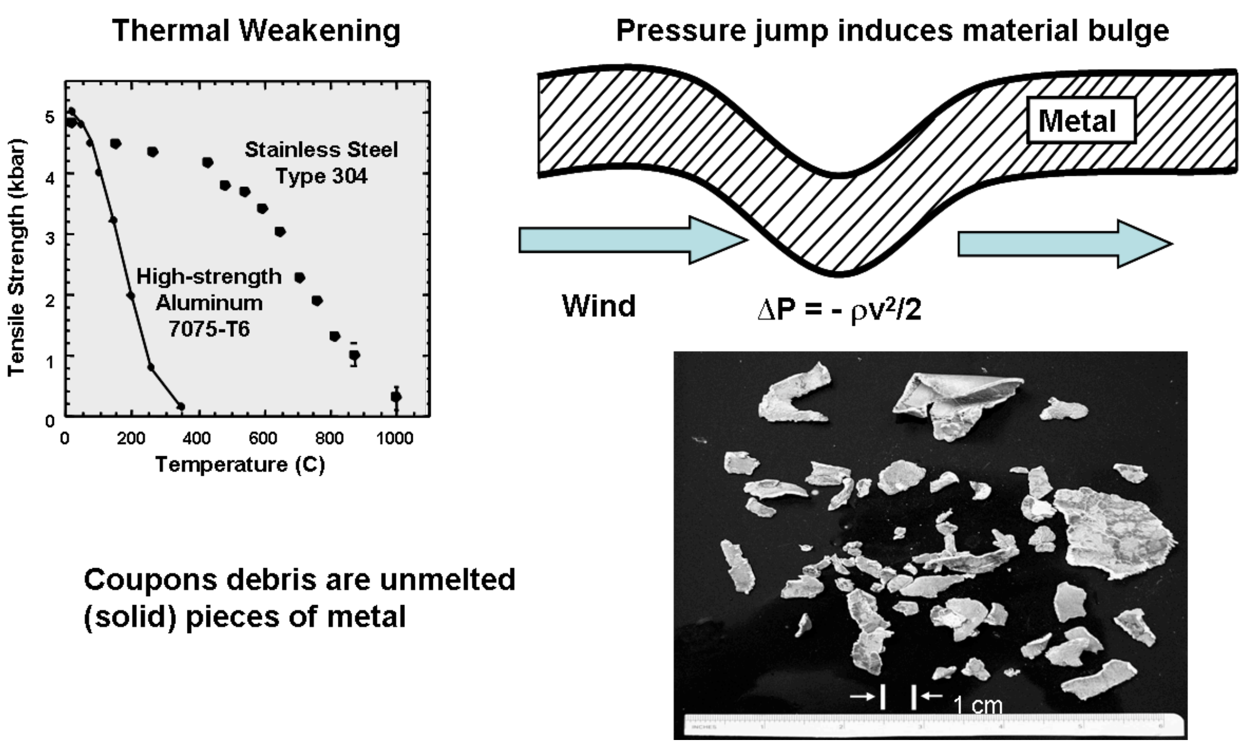


Figure 5. Plastic flow and wind dynamic effects determine how the target breaks

IV. Self-sustaining combustion:

Experiments with titanium materials have demonstrated self-sustaining combustion when the laser spot is of adequate size, providing enough surface area to sustain this effect. In this particular scenario, the burning temperature is above the melting temperature of the titanium. Once again, the introduction of wind induces a rippling of the melted surface, increasing the surface area of the exposed material and enhancing the self-sustaining combustion process.

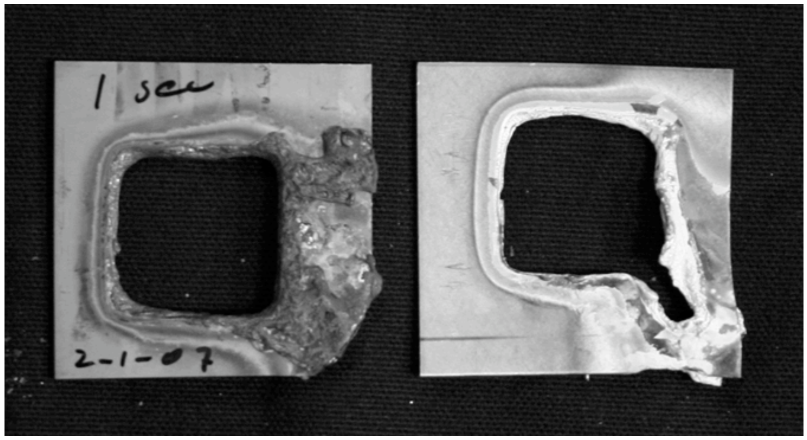


Figure 6. Thin titanium sheets (2” square) demonstrates combustion after laser turn-off

CONCLUSION

As we fully acknowledge, the interaction of lasers with materials is a very complex and non-linear phenomena, as evidenced by the four target destruction methods described above. It is very sensitive to the specifics of the situation; target details, environmental parameters, etc. Much of the information available today is purely empirical in nature, providing useful information and understanding, but severely lacking in its ability to predict what will happen in a slightly different situation. Obviously, a science-based understanding is fundamental to developing models validated by experiment, which can provide useful understanding of laser-material (target) interaction under a wide variety of situations and scenarios. A fundamental scientific study can help to find factors important in the understanding of lethality of specific targets under specific conditions, in order to determine (if necessary) the specific experiments needed to develop the final destruction requirements for a given operational scenario.

ACKNOWLEDGMENTS

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